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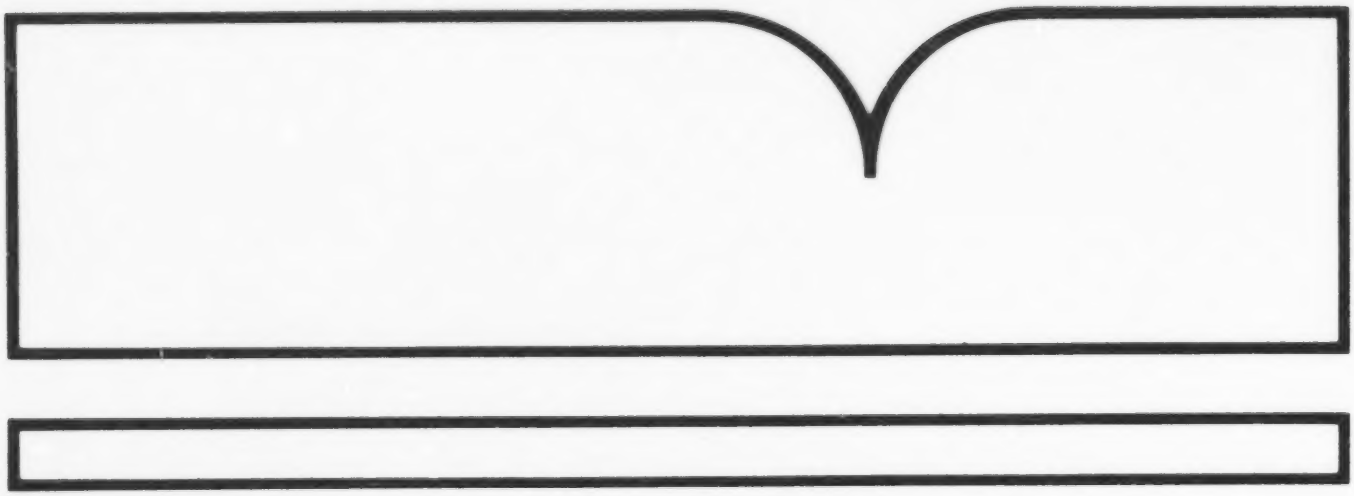

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FLUE GAS CLEANING OF MUNICIPAL WASTE COMBUSTION GASES: PERFORMANCE AND EMISSIONS

By

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16. ABSTRACT The paper discusses available control technologies in the U.S., Japan, and Western Europe and their expected effectiveness in controlling the various pollutants emitted during the combustion of municipal waste. Increasing concern over the potential hazards of landfills for disposing of water and the diminishing sites available for new landfills have led to incineration for destroying hazardous waste and reducing the volume of other wastes. While wastes-to-energy conversion can be a benefit, incineration produces air pollutant emissions which can be minimized by in-furnace and post-combustion control technologies. As potential regulation of both hazardous air pollutants and acid rain precursors in the future may force closing of operating incinerators or their costly retrofitting with new or improved controls, planning for new or improved incinerators should consider the environmental controls available to minimize costs and facilitate the required actions if stricter regulations are imposed.

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ABSTRACT

Increasing concerns over the potential hazards of landfills for disposing of waste and the diminishing sites available for new landfills have led to incineration for destroying hazardous waste and reducing the volume of other wastes. While wastes-to-energy conversion can be a benefit, incineration produces air pollutant emissions which can be minimized through in-furnace and post-combustion control technologies. As potential regulation of both hazardous air pollutants and acid rain precursors in the future may force closing of operating incinerators or their costly retrofitting with new or improved controls, the planning for new or improved incinerators should consider the environmental controls available to minimize costs and facilitate the required actions if stricter regulations are imposed. Available control technologies in the U.S., Japan, and Western Europe and their expected effectiveness in controlling the various pollutant emissions are discussed.

For presentation at the AIChE Annual Meeting in New York, NY, on November 19, 1987.

This paper has been reviewed in accordance with the U.S. Environmental Protection Agency peer and administrative review policies and approved for presentation and publication.

INTRODUCTION

Generators of hazardous wastes, substantial volumes of non-hazardous wastes, or mixtures of both have several available disposal options, all of which promise to become increasingly expensive in the future. Long-term storage and landfilling have inherent liabilities and steadily increasing costs as available sites diminish and regulations drive up operating costs. Except for limited recycle/reuse opportunities, the majority of thermally destructible wastes will probably be incinerated in special purpose furnaces, or mixed with fossil fuels and/or larger volume combustible wastes and burned in conventional steam boilers or water-wall incinerators. In many cases, cogeneration of steam and electricity from waste combustion will be the most economically attractive long-term waste disposal option.

In reducing waste volume and destroying potentially hazardous components, air pollution is an unavoidable by-product. Nearly complete destruction (99.99%) of hazardous wastes by combustion is now required. However, trace quantities of products of incomplete combustion, especially dioxins and furans, are not currently regulated by the U.S. EPA. Further, high destruction efficiencies require high temperature and increased turbulence (good mixing). Both of these promote increased oxides of nitrogen (NO_x), which are acid rain precursors. Oxidation of fuel nitrogen, sulfur, and halogens produces additional NO_x, sulfur oxides (SO_x), and acid gases, all suspected contributors to acid rain. Non-combustibles such as trace metals (especially mercury, lead, arsenic, and chromium) are all potentially emitted with fly ash.

Given the potential for these classes of pollutants--trace hazardous organics, acid gases, trace heavy metals, and fly ash--the air pollution control strategy selected must have the capability of multi-pollutant control in order to minimize costly retrofit or upgrading to meet possible future regulations. The residues, although small in volume relative to unburned wastes, contain concentrated pollutants which must be disposed of in an environmentally safe manner, but residue disposal is not addressed here.

CURRENT REGULATORY STATUS

Requirements of the individual states differ, and the U.S. lags behind other industrial nations in regulating emissions from waste combustion as shown

in Table 1. Local regulations or permit conditions frequently determine the types of combustor and emission controls required. In the U. S., for example, only particulate matter is currently regulated by Federal Standard,[1] but typical permits at the local or state level have limited carbon monoxide, SO_x, and NO_x emissions, and more recently have covered trace metals, hydrocarbons (particularly dioxins), and acid gases (hydrochloric and hydrofluoric acids). Recent installations in the U. S. have included technologies specifically targeted to reduce unburned hydrocarbons in the furnace as well as tail-end processes to remove acid gases, SO_x, and particulate matter.[2] Particulate matter controls are currently being permitted at 45 to 65% of the allowable emissions under current Federal Standards, reflecting growing concern over trace metals which tend to partition in the finer particles.[3] One recent U.S. installation included an in-furnace reduction technique for reducing NO_x.[4]

In Western Europe, particularly West Germany, similar technologies have been installed for nearly a decade due to local permit requirements and national standards which were recently set by Federal regulations summarized in Table 1. Many of the technologies currently offered in the U.S. and described later in this paper are licensed from European vendors such as NIRO, Flakt, and Deutsche Babcock. Japanese installations have shown similar trends to those in Europe but additionally feature an add-on, catalytic reduction step for NO_x removal, using Japanese technology developed originally for steam electric generators.[5]

EMISSION CONTROL TECHNOLOGIES

In-Furnace Techniques

Of paramount concern is the destruction of combustible and hazardous components which also diminish the amounts of potentially hazardous products of incomplete combustion, or toxic organics. A program is now underway within the U.S. EPA to determine good combustion practices for incinerators within the next year. The goals of the program include establishing relationships for efficient combustion, air/fuel mixing criteria, air injector designs, excess air and turndown restrictions, start-up and shutdown procedures, and monitoring to verify compliance with these guidelines.

For NO_x control, one in-furnace technique is currently in use in Japan and at one installation in the

TABLE 1. SELECTED EMISSIONS STANDARDS FOR MUNICIPAL WASTE INCINERATORS

	U.S.[a]	California	Connecticut	Michigan	West Germany	Sweden
Solid Particulate Matter, gr/dscf (mg/m^3)	0.046 (113)	0.01[b] (25)	0.015 (37)	0.015 (37)	0.012 (30)	0.008[c] (20)
Carbon Monoxide, ppm	---	---	---	113(24-hr avg)	80	---
Hydrogen Chloride	---	30 ppmv (wet or dry scrubbers req'd)	90% reduction	90%	31 ppmv (50 mg/Nm^3)	63 ppmv (100 ng/Nm^3)
Sulfur Dioxide, ppm	---	30	170	86	35 (200 mg/Nm^3)	New SO_2 limits reduce all acids significantly
Dioxins Measured as 2,3,7,8 - tetra-chlorodibenzo-p-dioxins (TCDD)	---	---[d]	---[e]	---	---	Existing plants: 0.5-2.0 ng/Nm^3 New plants: 0.1 ng/Nm^3
Total Organics, mg/m^3	---	---	---	---	20	---
Mercury + Cadmium + Thallium, mg/m^3 (includes vapors)	---	---	---	---	0.2	0.08 (Hg only)
Gas Correction	12% CO_2 dry	12% CO_2 dry	12% CO_2 dry	12% CO_2 dry	11% O_2 dry	10% CO_2 dry

[a]Revised NSPS for pollutants scheduled to be proposed in 1989.
[b]California regulations permit more stringent local limits. Two state guidelines are reported: 0.01 gr/dscf (25 mg/m^3) for total solid particulates (TSP) and 0.008 gr/dscf (20 mg/m^3) for particles less than 2 μm.
[c]This limit and those below are from the Swedish Environmental Protection Board's "Temporary Emission Goals," July 1986.
[d]Pollutant control requires use of the Best Available Control Technology (BACT), although no technology has yet been specified.
[e]The use of dry gas scrubbers and baghouses is expected to improve removal over ESPs alone.

U.S. Known as Thermal DeNO$_x$, it involves injecting ammonia in the upper furnace to achieve selective reduction of NO$_x$ (see Figure 1).[4] The ammonia/NO$_x$ reactions are extremely sensitive to temperature so that the injection location must be carefully selected. Also there is generally some slip of ammonia (i.e., ammonia which does not react with NO$_x$).

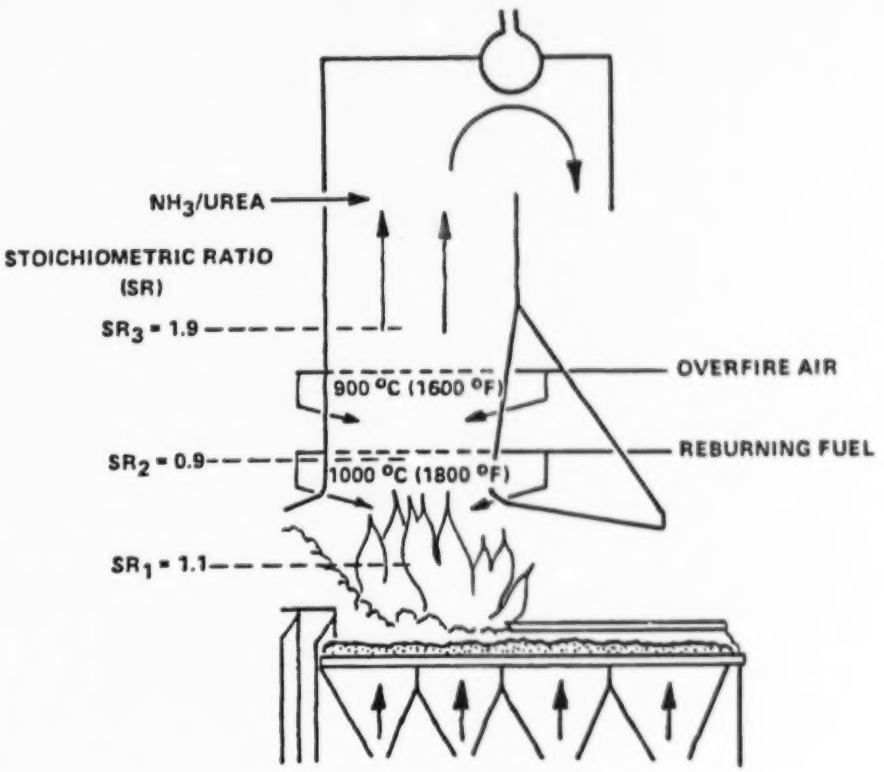


Figure 1. Reburning and Thermal DeNO$_x$ applied to a waste incinerator.

Another promising NO$_x$ control concept is reburning with an auxiliary fuel such as natural gas. The process could potentially be applied to waste incinerators as shown in Figure 1. The individual stoichiometric ratio (SR$_i$) terms in this figure refer to the air/fuel stoichiometric ratio (SR) with SR less than 1.0 representing fuel-rich conditions. Enough reburning fuel should be injected at a location low in the furnace to create a hot, slightly oxygen-starved zone. The overfire air is injected above the reburning zone to complete the combustion process. Reburning can be combined with ammonia or urea injection to optimize NO$_x$ reduction. In addition

to NO_x reduction, reburning has the potential for destroying organic compounds due to the high flame temperature and high concentration of flame radicals existing in the reburning zone.[6]

Particulate Matter Control

Particulate matter control for solid waste combustors is practiced in all technologically advanced countries. The dominant system in the U. S. is the electrostatic precipitator (ESP), accounting for about 75% of all systems. With ESPs, very low emission levels are achievable; < 45 mg/Nm^3 (< 0.02 gr/dscf) at high ratios of collector plate surface area to gas flow volume; i.e., in the range of 170 min./m (52 min./ft) or greater.

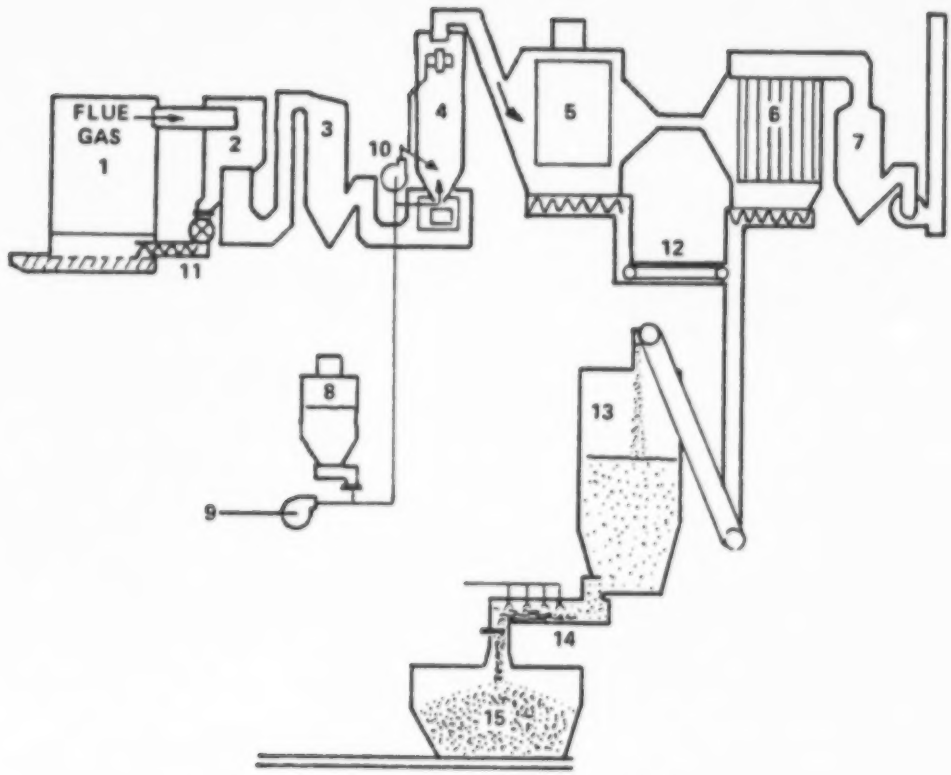
Wet scrubbers (venturis) are relatively ineffective for particle control, removing 80 to 95% at normal operation. Very high pressure losses are required to remove fine particles, and the erosion and corrosion potential in acidic gas streams makes the venturi a poor choice from economic and reliability perspectives.

Fabric filters are seldom used unless upstream sorbent injection is practiced, because of the perceived failures caused by hot gases, spark carryover, or sticky particles. However, fabric filters are capable of control to < 45 mg/Nm^3 without the operational upsets due to varying fuel and ash composition that adversely affect ESPs.

Acid Gas Control

Control of acid gases (HCl, HF, and SO_2) requires scrubbing or devices for gas/liquid or gas/solid contact. Water alone is a reasonably effective sorbent for very reactive acid gases such as HCl and HF, but an alkali sorbent (or control of liquid pH to 5 or higher) is necessary for substantial SO_2 control. Totally dry sorbents require substantial residence time in the gas for effective acid gas control. Injection of sorbent into a duct must be complemented by a fluid-bed reactor, humidification, a fabric filter dust collector, or combinations of these to be effective. Figures 2 and 3 illustrate typical dry sorbent injection systems in use in Western Europe.

Spray drying or semi-dry injection of sorbent is more effective than dry injection, with increasing acid gas control as the approach to saturation temperature is decreased, either by waste heat recovery or water injection/humidification. The most effective control



1. FURNACE AND BOILER
2. PRECOLLECTOR
3. WASTE HEAT BOILER NO. 1
4. REACTOR
5. ELECTROSTATIC PRECIPITATOR
6. FABRIC FILTER
7. WASTE HEAT BOILER NO. 2
8. LIME SILO
9. LIME FEEDING
10. LIME RECIRCULATION
11. COARSE DUST CONVEYING
12. FINE DUST CONVEYING
13. DUST SILO
14. DUST HUMIDIFIER
15. DUST BIN

Figure 2. Dry absorption system, Malmo, Sweden.

of acid gases is by alkali scrubbers operating at saturation (wet scrubbing), but this has to be weighed against the amount of waste water generated and its treatment. Figure 4 illustrates a typical spray dryer system for acid gas removal.

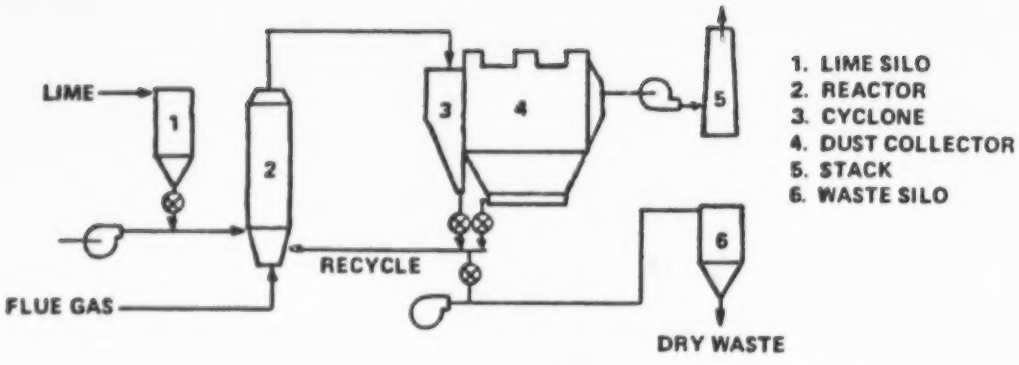


Figure 3. Circulating fluid-bed absorption (dry) process.

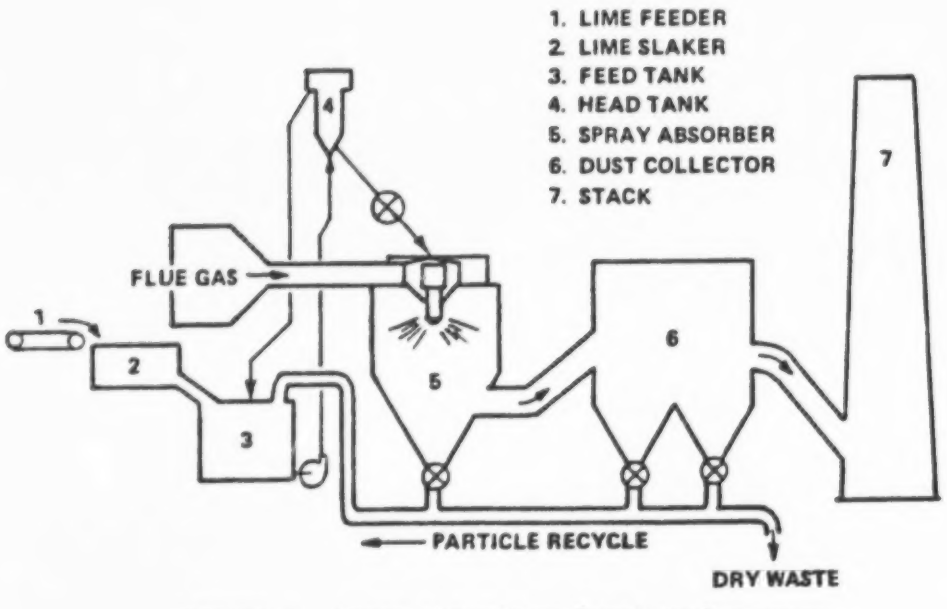


Figure 4. Spray absorption (semi-dry) process.

Combined semi-dry/dry scrubbers control acid gases perhaps more effectively than once-through spray drying and are probably similar in effectiveness to spray drying with recycle, depending on the approach to saturation temperature. Combined semi-dry/wet systems, such as spray dryer/venturi(s) combinations, are potentially the most effective systems for acid gas control but become increasingly complex as the number of targeted

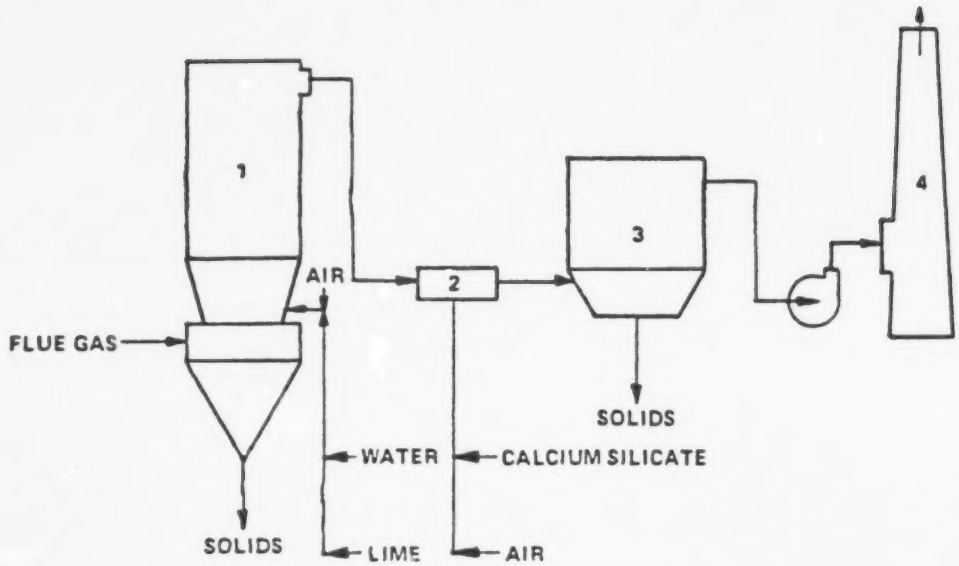
pollutants increases. Table 2 summarizes the above discussion. The reader is cautioned that the reagent requirements and solid/liquid wastes produced are not considered, and this table only reflects the systems as operated. Any of these techniques may be enhanced by more reactive sorbents or operation at more favorable temperatures. Figures 5 and 6 illustrate the combination semi-dry/dry and semi-dry/wet scrubbing systems.

TABLE 2. EFFECTIVENESS OF ACID GAS CONTROLS (% REMOVAL)

Control System	Pollutant		
	HCl	HF	SO_2
Dry Injection + Fabric Filter (FF)[a]	80	98	50
Dry Injection + Fluid-Bed Reactor + ESP[b]	90	99	60
Spray Dryer + ESP	95+	99	50-70
(Recycle)[c]	(95+)	(99)	(70-90)
Spray Dryer + Fabric Filter	95+	99	70-90
(Recycle)[c]	(95+)	(99)	(80-95)
Spray Dryer + Dry Injection + ESP or FF[d]	95+	99	90+
Wet Scrubber[e]	95+	99	90+
Spray Dryer + Wet Scrubber(s) + ESP or FF[e]	95+	99	90+

[a] T = 160-180°C (320-356°F)
[b] T = 230°C (446°F)
[c] T = 140-160°C (284-320°F)
[d] T = 200°C (392°F)
[e] T = 40-50°C (104-122°F)
T = the temperature at the exit of the control device.

In summary, effective control of acid gases is possible with dry, semi-dry, or wet scrubbers. HCl and HF are relatively easy to control, while SO_2 control is more difficult and is favored by wet or semi-dry systems with lower flue gas temperatures. Although not discussed due to lack of data, very effective sulfur trioxide (SO_3) control seems possible with a spray dryer.



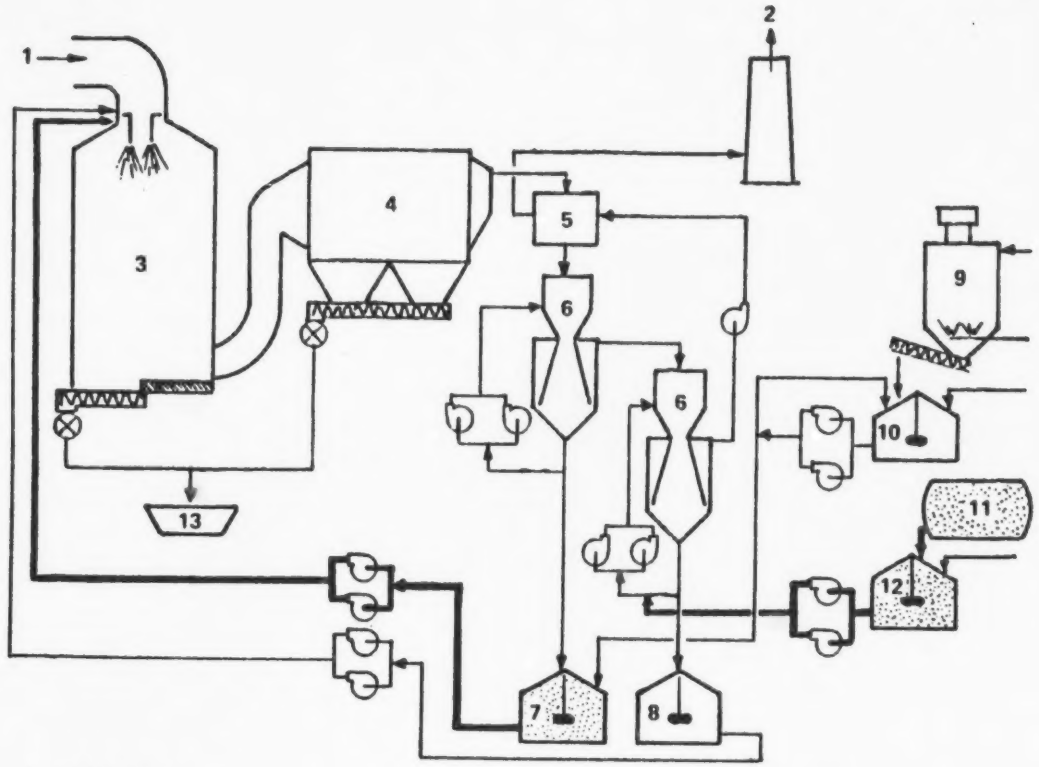
1. QUENCH REACTOR (SPRAY DRYER)
2. DRY VENTURI
3. BAGHOUSE
4. STACK

Figure 5. Semi-dry/dry scrubber.[7]

Should SO_3 control also become a concern, systems which contact the gas with wet or dry sorbent prior to a particulate control device should be encouraged. This approach is suggested because, after alkali scrubbing, SO_3 apparently becomes an aerosol and is amenable to capture. Control systems with particle collectors uptream of the scrubber have historically reported poor SO_3 control effectiveness.

Post-Combustion NO_x Control

Probably the most difficult pollutant to control by flue gas scrubbing is NO_x, primarily due to unreactive NO which comprises 95% or more of the total uncontrolled NO_x. Largest post-combustion NO_x reductions are therefore achieved by selective catalytic reduction (SCR) which currently must be preceded by acid gas and heavy metals control to be effective. If the thermal penalties of precleaning are acceptable, then SCR can remove 80-90% of NO_x with a NH_3/NO molar ratio of 1.0 and about 5 ppmv NH_3



1. FLUE GAS
2. EXHAUST GAS
3. SPRAY DRYER
4. ELECTROSTATIC PRECIPITATOR OR FABRIC FILTER
5. GAS/GAS HEAT EXCHANGER
6. VENTURI SCRUBBER
7. NEUTRALIZATION TANK
8. SLUDGE TANK
9. LIME SILO
10. LIME SLAKER
11. SODIUM HYDROXIDE STORAGE
12. SODIUM AIR TANK
13. DRY WASTE

Figure 6. Semi-dry/wet scrubber.

slip. Use of special lower temperature, HCl-resistant catalysts in the future can make SCR even more attractive.[5] Potentially less effective and more complicated NO_x control may be achieved by an oxidation step integrated into sodium- or magnesium-based wet scrubbing. Due to the liquid waste potential, this may be best applied to the combination semi-dry/wet scrubber system shown in Figure 6, and NO_x control of 30 to 50% would be expected. Figure 7 illustrates SCR as applied to incineration flue gas in Japan.

Post-Combustion Organic Pollutant Control

Control of dioxins and furans, as well as other trace organic compounds, is not well understood because the mechanism of capture is not known. Likely, condensation and capture as a particle is significant, and attack and capture by caustic reagents is also probable. These capture phenomena are best addressed by lowering flue gas temperatures, subjecting flue gas to caustic sorbent, and collecting the product in a highly efficient particle collector. Limited data show that spray drying followed by fabric filtration is very effective for organic vapor control and superior to the spray drying/ESP system. Also lower flue gas temperatures favor increased control of organics. Reference 8 is a good discussion of these observations. The results are summarized in Table 3, where CDD refers to chlorinated dibenzo-para-dioxins and CDF to chlorinated dibenzofurans.[8]

Limited data have been collected on control device efficiencies for dioxins and furans, with only outlet concentrations being reported for most tests. Unfortunately, test data and methodologies are lacking to compare the effectiveness of various control systems for organic pollutants. However, the superiority of a sorbent on a fabric filter for control is evident from Table 3. The data shown were based on tests in a single pilot plant, and thus should be used with caution.[8]

Heavy Metals Control

The control of heavy metals is similar to organic pollutant control in that effective control of particles and low flue gas temperatures are major factors. Sorbents, however, are not suspected to play a major role. Toxic metals enter the collectors as solids, liquids, and vapors and, as the flue gas cools, the vapor portion converts to collectible solids and liquids. Figure 8 illustrates various heavy metals as they appear in flue gas and their relative

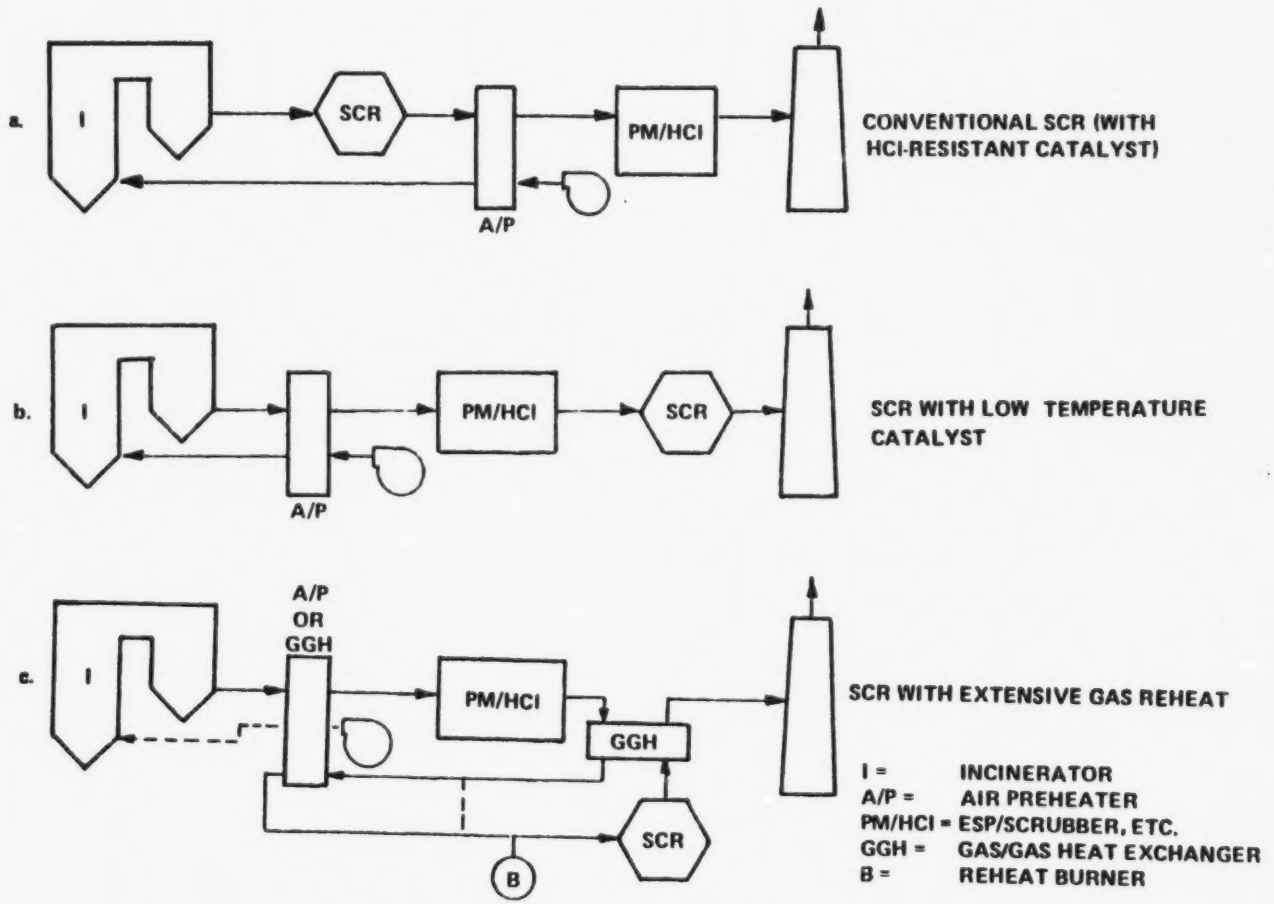


Figure 7. SCR options for municipal incinerators.

theoretical concentrations (vapor pressures) as a function of flue gas temperature.[9]

TABLE 3. SPRAY DRYER CONTROL OF SELECTED ORGANIC POLLUTANTS[8]

Compound	Control System (% Removal) SD + ESP	SD + FF @ High Temp.	SD + FF @ Low Temp.
Dioxins:			
tetra CDD	48	< 52	> 97
penta CDD	51	75	> 99.6
hexa CDD	73	93	> 99.5
hepta CDD	83	82	> 99.6
octa CDD	89	NA	> 99.8
Furans			
tetra CDF	65	98	> 99.4
penta CDF	64	88	> 99.6
hexa CDF	82	86	> 99.7
hepta CDF	83	92	> 99.8
octa CDF	85	NA	> 99.8

From Figure 8, it can be deduced that decreasing the flue gas temperature below 200°C (392°F) and high efficiency particulate collection should result in a very large reduction of metals, except for mercury (Hg), arsenates $(As_2O_3)_2$, and selenium (SeO_2 and Se_6). Corresponding reductions of these compounds proceed dramatically as temperatures are lowered. With the metals at their saturation temperatures, each is expected to be reduced by 90% for each additional temperature drop of 11 to 17°C (20 to 30°F). If this temperature effect is true, then wet scrubbing or wet/dry scrubbing which operates at saturation [40°C (104°F)] should be highly effective for total heavy metals control, while most dry and semi-dry systems should be just as effective for practically all metals except mercury, arsenic, and selenium. The dry and semi-dry systems should achieve some capture of mercury, arsenic, and selenium, with the degree of capture increasing with decreasing flue gas temperature.

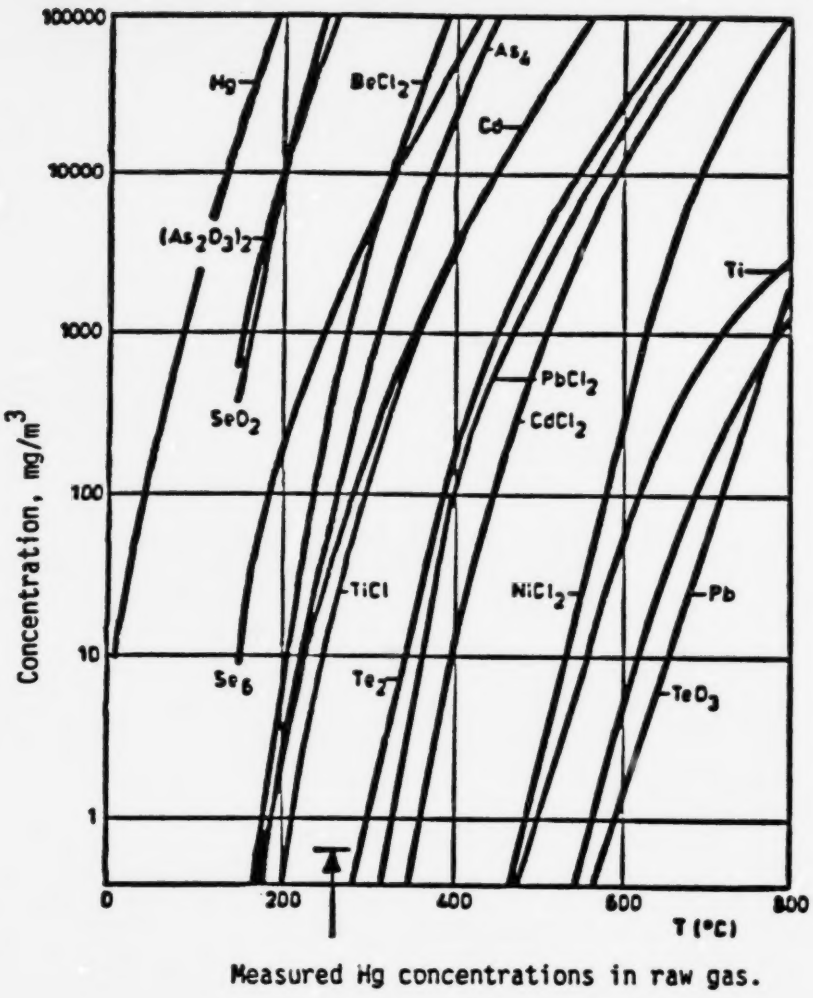


Figure 8. Saturation points of metals and metal compounds.[9]

Reported metals control data generally show 95-98% control or greater for most heavy metals except mercury. Vapor-phase mercury control has been reported as: 75-85% control with spray dryer plus baghouse; and 35-45% control with spray dryer plus ESP.[9] This is important in that vapor control is possible with fabric filters and ESPs, although limited data show the former to be clearly superior. Wet scrubbers would appear to be ideal for mercury control, but the collection of mercury vapors via condensation and capture is not well documented. Therefore, the choice of the most effective mercury control is still the subject of controversy (see Reference 3).

SUMMARY

In destroying wastes by incineration, several classes of air pollutants are emitted which will likely require control or at least consideration for control by permitting agencies. The pollutants include trace hazardous organics, acid gases, trace heavy metals, and particulate matter. Various in-furnace and post-combustion technologies are available to control these pollutants, but the degree of control complexity increases with the number of pollutants to be controlled. Operators of existing incinerators should be aware of these technologies for possible future retrofit requirements, while those planning incineration projects should design these facilities to embrace as many of the concepts described as practical, in order to meet permit requirements with minimum delay.

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